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Voxel based occlusion mapping and plant area index estimation from airborne laser scanning data

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Highlights: We introduce a ray-tracing based approach for mapping occluded areas in airborne laser scanning (ALS) data for a temperate mixed forest in Switzerland. Furthermore, the approach showed promising results towards a three-dimensional retrieval of plant area index (PAI) from ALS data.

Key words: *ALS, forestry, PAI, ray-tracing, voxel traversal*

Introduction

Accurate three-dimensional information of canopy structure contributes to better understanding of radiation fluxes within the canopy and the physiological processes associated with it. Small-footprint airborne laser scanning (ALS) data proved valuable for characterizing the three-dimensional structure of forest canopies [1]. Nevertheless, very few studies actually analysed what the ALS system was able to actively observe and which parts were occluded from the system due to dense vegetation or scanning patterns [2]. The information about occluded areas could be of importance and could serve as a quality layer for characterizing the three-dimensional structure of the forest canopy. We therefore introduce a ray-tracing based approach for characterizing the ALS observation pattern inside a three-dimensional voxel grid. The study was performed on the Laegeren test site (47° 28' 43.0 N, 8° 21' 53.2 E, Switzerland), a temperate mixed forest characterized by steep slopes and high species diversity. Both, leaf-on and leaf-off ALS acquisitions were available for analysing seasonal differences in occluded areas.

As a key canopy structural characteristic, plant area index (PAI) serves as an important input parameter for radiative transfer modelling. PAI is defined as half the total area of leaves and woody materials per unit ground area [3]. ALS proved valuable in deriving PAI using simple approaches based on the Beer-Lambert law of light extinction and the estimation of penetration rate of the laser pulses through the canopy (e.g. in [4]). By relying on physically based approaches, requirements for field calibration is minimized which is of special interest for large area sampling. In this study, we analysed the possibility of deriving voxel-based PAI estimation from ALS measurements using the proposed ray-tracing approach.

Materials and Methods

ALS data were acquired over the Laegeren test site under leaf-off (April 10th 2010) and leaf-on (August 1st 2010) conditions. Both campaigns were flown with a nominal height of 500 m above ground and a beam divergence of approximately 0.5 mrad resulting in a footprint size of 0.25 m. The wavelength of the laser was 1550 nm. A flight strip overlap of approximately 50% finally leads to a mean point density of 20 m⁻² in the leaf-off and 40 m⁻² in the leaf-on dataset. The positional accuracy of the ALS data was <0.15 m in vertical and <0.5 m in horizontal direction. Plot-level PAI estimates from digital hemispherical photographs (DHPs) were available for validation purposes.

For the estimation of the voxel-based PAI, the scene was first divided into a three-dimensional voxel grid with a predefined voxel dimension. Afterwards, each laser pulse was traced through the voxel grid using a simple voxel traversal algorithm first introduced in [5] and adapted for the use with terrestrial laser scanner (TLS) in [6]. The algorithm was adapted for the use with ALS, considering multiple returns per pulse. For each voxel, the number of pulses able to traverse the voxel with (N_{hit}) and without (N_{miss}) a laser return was recorded. Additionally, the number of pulses theoretically traversing the voxel that were obstructed from the surrounding canopy was registered as the number of occluded pulses (N_{occ}). By considering N_{hit} , N_{miss} , and N_{occ} , one is able to extract a voxel grid with classifications, providing the observable and occluded regions for that particular ALS survey. The classification scheme follows the approach described in [6] and is further described in Table 1.

Considering N_{hit} and N_{miss} , a penetration rate through the voxel can be estimated. Combined with Beer-Lambert law of light extinction, a PAI can be estimated adapting the approach described in [4] to a voxel based approach:

$$PAI = -\frac{1}{k} * \ln\left(\frac{N_{miss}}{N_{miss} + N_{hit}}\right) \quad (1)$$

Table 1: Classification of voxel cells (following [6])

	Number of		
	Returns (N_{hit})	Penetrations (N_{miss})	Occlusions (N_{occ})
Observed	>0	≥ 0	≥ 0
Empty	$=0$	>0	≥ 0
Hidden	$=0$	$=0$	>0
Unobserved	$=0$	$=0$	$=0$

where k is the extinction coefficient defined by:

$$k = \frac{G(\theta, \theta_L)}{\cos \theta} \quad (2)$$

where G is the projection of foliage area that depends on the leaf normal angle (θ_L) and the incidence angle of the laser pulse (θ) [7]. For the PAI estimation, N_{miss} and N_{hit} were further weighted according to the number of returns registered by the pulse, following the assumption, that a pulse with n returns can be divided into n equal parts (e.g. for a pulse with 7 returns, each return counts as $1/7^{\text{th}}$ N_{hit}). N_{miss} and N_{hit} were further weighted according to their path length through the considered voxel. For the case, where N_{miss} is zero, the above model saturates. Therefore, N_{miss} was replaced by the smallest possible value greater than zero (e.g. $1/7$ as the maximum number of returns per laser pulse was 7).

Results and Discussion

In Figure 1 the voxel classification output of the proposed voxel traversal algorithm is shown for a 300 m transect with one voxel depth (voxel dimension = $1 \times 1 \times 1$ m). Only voxels observed with a laser return (N_{hit}) and occluded voxels (N_{occ}) are shown. Occluded voxels are shown in yellow to red. Observed voxels with a registered laser return in them are shown in green to blue. The redder the occluded voxels are, the more pulses would have theoretically traversed the voxels, if they were not obstructed by the canopy. The bluer the voxels are, the more laser returns were registered by the ALS system inside the corresponding voxel. The results for both leaf-on and leaf-off conditions are shown. The occluded areas are much more dominant under leaf-on than under leaf-off conditions, as the laser pulses are much more obstructed by the denser canopy compared to the

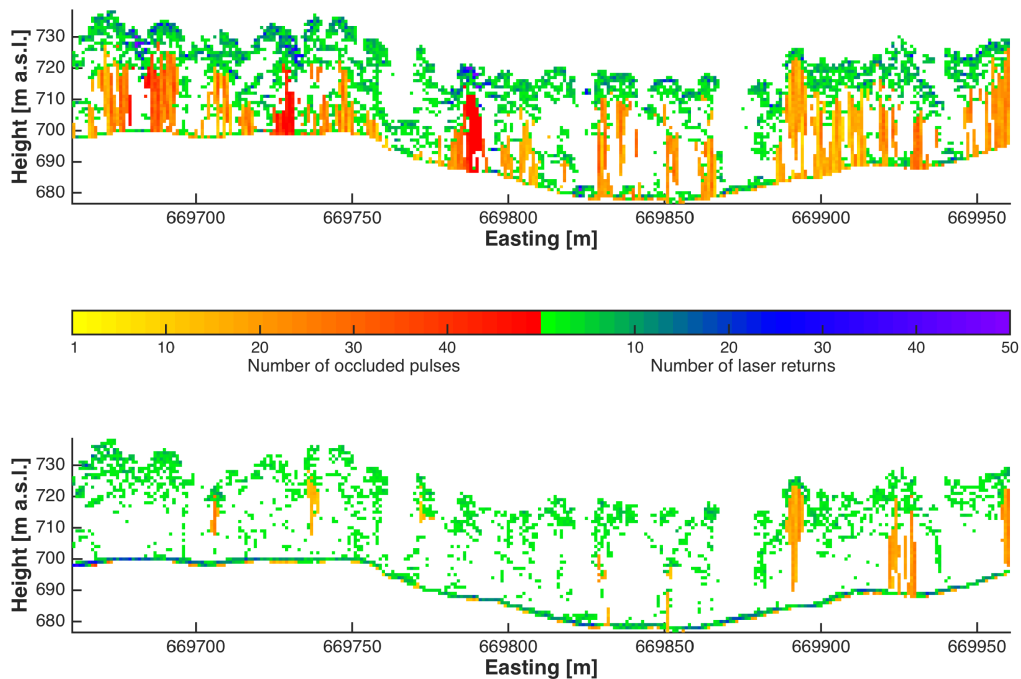


Figure 1: Voxel classification result for a 300 m transect with one voxel depth (1 m voxel dimension). Yellow to red denotes occluded voxels not visible for the ALS system and green to blue show the number of laser returns inside voxels, that were observed from the ALS. Top: Voxel classification for leaf-on condition. Bottom: Voxel classification for the same transect in leaf-off condition. Coordinates are in the Swiss national grid CH1903 / LV03

leaf-off case. The remaining occluded areas in the leaf-off case are mostly due to coniferous trees still obstructing laser pulses from penetrating into the canopy. In both conditions, scanning patterns (scan-angle, incidence angle, local incidence angle, pulse density) are believed to be a further cause for occlusion in the ALS dataset, especially in rugged terrain as found in our study site. Furthermore, the chosen voxel dimension affects the detected occluded area, as the possibility for a pulse traversing a voxel increases with increasing voxel size.

As the voxel classification results for leaf-on and leaf-off conditions are to some extent complementary, occluded areas in the leaf-on case could be filled using the information from the leaf-off condition. This is especially of importance when trying to characterize understory vegetation from ALS measurements [2].

The proposed PAI estimation approach showed promising results, with good correlation to the available plot-level PAI estimates from DHP measurements, when aggregating the vertically resolved PAI values to a two-dimensional map. Nevertheless, some voxels showed unrealistically high PAI values when a large amount of laser returns were registered for the corresponding voxel, but no – or just very few – laser pulses were able to penetrate the voxel. This is mostly the case for voxels which are totally filled e.g. by large branches or a tree trunk. Approaches to overcome these issues are currently investigated. For instance, the incorporation of the available full-waveform features (e.g. intensities, full width at half maximum FWHM) and the estimation and compensation of a clumping index considering the distribution of the laser returns inside the voxel could be used in this context.

The positional accuracy of the laser point-cloud is assumed to be a source of uncertainty in this ray-tracing approach, especially when considering small voxel sizes of less than 1 m. We therefore restricted the minimum voxel size to 1 m. Increasing voxel dimensions were found to increase the robustness of the PAI retrieval.

Conclusion

We proposed a simple voxel-traversal algorithm for mapping occluded areas from small-footprint ALS inside three-dimensional space and tested the algorithm for the use in retrieving vertically resolved PAI estimates. The proposed approach showed that the amount of occluded voxels is highly dependent on the season of ALS acquisition. Furthermore, laser acquisition patterns were found to have an influence on the amount of occluded areas inside the forest canopy. The proposed PAI estimation approach showed promising results when aggregated and compared to 2D estimation of PAI using hemispherical photographs. Yet, for very dense vegetation and voxels totally filled with wood materials, the proposed approach highly overestimates PAI, leading to unrealistically high values for the analysed study site. The next steps will include the analysis of the clumping inside each voxel and trying to compensate for the PAI overestimation. Also further analysis on the influence of pulse density, scan and incidence angle on the occluded areas and the penetration depth of the laser pulses will be conducted. We further plan to incorporate the retrieved PAI voxel grid in a radiative transfer model to analyse the complex three-dimensional radiative budget inside the forest canopy.

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References

- [1] Schneider, F. D., Leiterer, R., Morsdorf, F., Gastellu-Etchegorry, J.-P., Lauret, N., Pfeifer, N., & Schaepman, M. E. (2014). Simulating imaging spectrometer data: 3D forest modeling based on LiDAR and in situ data. *Remote Sensing of Environment*, 152, 235-250.
- [2] Korpela, I., Hovi, A., & Morsdorf, F. (2012). Understory trees in airborne LiDAR data – Selective mapping due to transmission losses and echo-triggering mechanisms. *Remote Sensing of Environment*, 119, 92-104.
- [3] Chen, J. M., Black, T. A., & Adams, R. S. (1991). Evaluation of hemispherical photography for determining plant area index and geometry of a forest stand. *Agricultural and Forest Meteorology*, 56, 129-143.
- [4] Solberg, S., Brunner, A., Hanssen, K. H., Lange, H., Næsset, E., Rautiainen, M., & Stenberg, P. (2009). Mapping LAI in a Norway spruce forest using airborne laser scanning. *Remote Sensing of Environment*, 113 (11), 2317-2327.
- [5] Amanatides, J., & Woo, A. (1987). A fast voxel traversal algorithm for ray tracing. *Eurographics*, 87 (3), 1-6.
- [6] Bienert, A., Queck, R., & Schmidt, A. (2010). Voxel Space Analysis of Terrestrial Laser Scans in Forests for Wind Field Modeling. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 38 (Part 5), 92-97.
- [7] Ross, J. (1981). *The radiation regime and architecture of plants stands*. Dr. W. Junk Publishers, The Hague.